

WHAT IS CLAIMED IS:

- 1 1. A hearing aid, comprising:
2 an input signal channel providing digital input signals;
3 a signal path adapted to process said digital input signals in accordance
4 with a predetermined signal processing algorithm to produce a digital output signal,
5 wherein said signal path further comprises at least one signal processing function
6 operating on a warped frequency scale, and wherein said at least one signal processing
7 function includes at least one spectral enhancement algorithm; and
8 an output conversion means adapted to convert said output signals to an
9 audio output.
- 1 2. The hearing aid of claim 1, wherein said at least one signal
2 processing function further comprises a plurality of cascaded all-pass filters.
- 1 3. The hearing aid of claim 1, wherein said warped frequency scale
2 approximates a Bark scale.
- 1 4. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 a plurality of cascaded all-pass filters, wherein said digital input signals
4 pass through said plurality of cascaded all-pass filters, and wherein said plurality of
5 cascaded all-pass filters output a sequence of delayed samples;
6 means for applying a frequency domain transform on said sequence of
7 delayed samples, wherein a warped sequence results from said frequency domain
8 transform applying means;
9 means for calculating a plurality of frequency domain level estimates from
10 said warped sequence;
11 means for calculating a plurality of frequency domain gain coefficients
12 from said plurality of frequency domain level estimates;
13 means for calculating a plurality of spectral enhancement gain coefficients
14 from said warped sequence;

15 means for calculating a plurality of compression-spectral enhancement
16 gain coefficients from said plurality of frequency domain gain coefficients and said
17 plurality of spectral enhancement gain coefficients;

18 means for applying an inverse frequency domain transform on said
19 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
20 domain filter coefficients of a compression gain filter result from said inverse frequency
21 domain transform applying means; and

22 means for convolving said sequence of delayed samples with said set of
23 time-domain filter coefficients to produce a digital output signal.

1 5. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
4 power spectrum comprised of said plurality of frequency domain level estimates to a
5 power greater than 1.

1 6. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
4 a plurality of peaks of said warped sequence.

1 7. The frequency-warped processing system of claim 6, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 8. The frequency-warped processing system of claim 4, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes
4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 9. The frequency-warped processing system of claim 4, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 10. The frequency-warped processing system of claim 4, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 11. The frequency-warped processing system of claim 4, further
2 comprising means for windowing said sequence of delayed samples, wherein a windowed
3 sequence of delayed samples results from said windowing means, and wherein said
4 warped sequence results from applying said frequency domain transform to said
5 windowed sequence of delayed samples.

1 12. The frequency-warped processing system of claim 4, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 13. The frequency-warped processing system of claim 12, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 14. The frequency-warped processing system of claim 4, said plurality
2 of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 15. The frequency-warped processing system of claim 4, said sequence
2 of delayed samples comprising 16 samples.

1 16. The frequency-warped processing system of claim 4, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 frequency domain transform applying means, said frequency domain level estimates
4 calculating means, said frequency domain gain coefficients calculating means, said
5 spectral enhancement gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said means for convolving said sequence of delayed
7 samples.

1 17. The frequency-warped processing system of claim 16, wherein said
2 digital processor comprises a software programmable digital signal processor.

1 18. The frequency-warped processing system of claim 4, wherein said
2 frequency domain transform applying means uses a transform selected from the group

3 consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel transforms,
4 and discrete cosine transforms.

1 19. The frequency-warped processing system of claim 4, further
2 comprising:

3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 20. The frequency-warped processing system of claim 4, further
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 21. A frequency-warped processing system, comprising:

2 an input signal channel providing digital input signals;

3 an input data buffer, said input data buffer holding at least one block of
4 data comprised of a portion of said digital input signals;

5 a plurality of cascaded all-pass filters, wherein a first block of said digital
6 input signals pass from said input data buffer through said plurality of cascaded all-pass
7 filters, and wherein said plurality of cascaded all-pass filters output a first sequence of
8 delayed samples;

9 means for windowing a first portion of said first sequence of delayed
10 samples, wherein a first windowed sequence of delayed samples results from said
11 windowing means;

12 means for applying a first frequency domain transform on said first
13 windowed sequence of delayed samples, wherein a first warped sequence results from
14 said first frequency domain transform applying means;

15 means for calculating a first plurality of frequency domain level estimates
16 of said first warped sequence;

17 means for calculating a first plurality of spectral enhancement gain
18 coefficients from said first warped sequence;

19 means for windowing a second portion of said first sequence of delayed
20 samples, wherein a second windowed sequence of delayed samples results from said
21 windowing means;

22 means for applying a second frequency domain transform on said second
23 windowed sequence of delayed samples, wherein a second warped sequence results from
24 said second frequency domain transform applying means;

25 means for calculating a second plurality of frequency domain level
26 estimates of said second warped sequence;

27 means for calculating a first plurality of spectral enhancement gain
28 coefficients from said first warped sequence;

29 means for summing said first and second plurality of spectral enhancement
30 gain coefficients, wherein a summed first and second plurality of spectral enhancement
31 gain coefficients results from said summing means;

32 means for summing said first and second plurality of frequency domain
33 level estimates, wherein a summed first and second plurality of frequency domain level
34 estimates results from said summing means;

35 means for normalizing said summed first and second plurality of frequency
36 domain level estimates, wherein a normalized first and second plurality of frequency
37 domain level estimates results from said normalizing means;

38 means for calculating a plurality of frequency domain gain coefficients
39 from said normalized first and second plurality of frequency domain level estimates;

40 means for calculating a plurality of compression-spectral enhancement
41 gain coefficients from said plurality of frequency domain gain coefficients and said
42 summed first and second plurality of spectral enhancement gain coefficients;

43 means for applying an inverse frequency domain transform on said
44 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
45 domain filter coefficients of a compression gain filter result from said inverse frequency
46 domain transform applying means; and

47 means for convolving a second sequence of delayed samples with said
48 time-domain filter coefficients, said second sequence of delayed samples produced by a
49 second block of said digital input signals passing from said input data buffer through said
50 plurality of cascaded all-pass filters, wherein a digital output signal results from said
51 convolving means.

1 22. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm raises a power spectrum comprised of said plurality of frequency domain level
5 estimates to a power greater than 1.

1 23. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm amplifies a plurality of peaks of said warped sequence.

1 24. The frequency-warped processing system of claim 23, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 25. The frequency-warped processing system of claim 21, said means
2 for calculating said first and second plurality of spectral enhancement gain coefficients
3 further comprising a spectral enhancement algorithm, wherein said spectral enhancement
4 algorithm includes means for forming an unsmeared warped sequence, and means for
5 calculating the difference between said warped sequence and said unsmeared warped
6 sequence.

1 26. The frequency-warped processing system of claim 21, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 27. The frequency-warped processing system of claim 21, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 28. The frequency-warped processing system of claim 21, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 29. The frequency-warped processing system of claim 28, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 30. The frequency-warped processing system of claim 21, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 31. The frequency-warped processing system of claim 21, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said first and second frequency domain
4 transforms, said means for calculating said first and second plurality of frequency domain
5 level estimates, said summing means, said normalizing means, said frequency domain
6 gain coefficients calculating means, said inverse frequency domain transform applying
7 means, and said convolving means.

1 32. The frequency-warped processing system of claim 21, wherein said
2 means for applying said first and second frequency domain transforms use a transform
3 selected from the group consisting of discrete Fourier transforms, fast Fourier transforms,
4 Goertzel transforms, and discrete cosine transforms.

1 33. The frequency-warped processing system of claim 21, further
2 comprising:

3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 34. The frequency-warped processing system of claim 21, further
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 35. The frequency-warped processing system of claim 21, wherein said
2 windowing means provides a 50 percent overlap of said first and second pluralities of
3 frequency domain level estimates.

1 36. The frequency-warped processing system of claim 21, wherein a
2 quantity of samples corresponding to said first block of said digital input signals is
3 equivalent to a quantity of first order all-pass filters corresponding to said plurality of
4 cascaded all-pass filters.

1 37. The frequency-warped processing system of claim 36, wherein said
2 first portion of said first sequence of delayed samples is comprised of a first half of said
3 first sequence of delayed samples and said second portion of said first sequence of
4 delayed samples is comprised of a second half of said first sequence of delayed samples.

1 38. A frequency-warped processing system, comprising:
2 an input signal channel providing digital input signals;
3 an input data buffer, said input data buffer holding a block of data of size
4 M comprised of a portion of said digital input signals;
5 a plurality of cascaded all-pass filters comprised of $2M$ cascaded all-pass
6 filters, wherein a first block of said digital input signals pass from said input data buffer
7 through said plurality of cascaded all-pass filters to form a first sequence of delayed
8 samples and wherein a second block of said digital input signals pass from said input data
9 buffer through said plurality of cascaded all-pass filters to form a second sequence of
10 delayed samples, and wherein said first sequence of delayed samples and said second
11 sequence of delayed samples form a combined sequence of delayed samples;
12 means for windowing a first portion of said combined sequence of delayed
13 samples, wherein said first portion is of size M , wherein a windowed sequence of delayed
14 samples results from said windowing means;
15 means for applying a $2M$ -point frequency domain transform on said
16 windowed sequence of delayed samples, wherein a warped sequence results from said
17 frequency domain transform applying means;
18 means for calculating a plurality of frequency domain level estimates of
19 said warped sequence;

20 means for calculating a plurality of frequency domain gain coefficients
21 from said plurality of frequency domain level estimates;
22 means for calculating a plurality of spectral enhancement gain coefficients
23 from said warped sequence;
24 means for calculating a plurality of compression-spectral enhancement
25 gain coefficients from said plurality of frequency domain gain coefficients and said
26 plurality of spectral enhancement gain coefficients;
27 means for applying an inverse frequency domain transform on said
28 plurality of compression-spectral enhancement gain coefficients, wherein a set of time-
29 domain filter coefficients of a compression gain filter result from said inverse frequency
30 domain transform applying means; and
31 means for convolving a second portion of said combined sequence of
32 delayed samples with said set of time-domain filter coefficients, wherein said second
33 portion is of size M, wherein a digital output signal results from said convolving means.

1 39. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm raises a
4 power spectrum comprised of said plurality of frequency domain level estimates to a
5 power greater than 1.

1 40. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm amplifies
4 a plurality of peaks of said warped sequence.

1 41. The frequency-warped processing system of claim 40, wherein said
2 spectral enhancement algorithm further comprises means for identifying said plurality of
3 peaks, said identifying means including means for applying a second-difference operator
4 to said warped sequence.

1 42. The frequency-warped processing system of claim 38, said means
2 for calculating said plurality of spectral enhancement gain coefficients further comprising
3 a spectral enhancement algorithm, wherein said spectral enhancement algorithm includes

4 means for forming an unsmeared warped sequence, and means for calculating the
5 difference between said warped sequence and said unsmeared warped sequence.

1 43. The frequency-warped processing system of claim 38, further
2 comprising a hearing aid, wherein the frequency-warped processing system is
3 incorporated within said hearing aid.

1 44. The frequency-warped processing system of claim 38, wherein said
2 plurality of frequency domain gain coefficients comprise a warped time-domain filter.

1 45. The frequency-warped processing system of claim 38, further
2 comprising a digital-to-analog converter, said digital-to-analog converter converting said
3 digital output signals to analog output signals.

1 46. The frequency-warped processing system of claim 45, further
2 comprising an output transducer, said output transducer converting said analog output
3 signals to an audio output.

1 47. The frequency-warped processing system of claim 38, said
2 plurality of cascaded all-pass filters comprising a plurality of first order all-pass filters.

1 48. The frequency-warped processing system of claim 38, further
2 comprising a digital processor, wherein said digital processor is adapted to provide said
3 windowing means, said means for applying said 2M-point frequency domain transform,
4 said means for calculating said plurality of frequency domain level estimates, said
5 frequency domain gain coefficients calculating means, said inverse frequency domain
6 transform applying means, and said convolving means.

1 49. The frequency-warped processing system of claim 38, wherein said
2 means for applying said frequency domain transform uses a transform selected from the
3 group consisting of discrete Fourier transforms, fast Fourier transforms, Goertzel
4 transforms, and discrete cosine transforms.

1 50. The frequency-warped processing system of claim 38, further
2 comprising:

3 an input transducer, said input transducer converting audio input signals to
4 analog input signals; and

5 an analog-to-digital converter, said analog-to-digital converter converting
6 said analog input signals to said digital input signals.

1 51. The frequency-warped processing system of claim 38, further
2 comprising:

3 a digital-to-analog converter, said digital-to-analog converter converting
4 said digital output signals to analog output signals; and

5 an output transducer, said output transducer converting said analog output
6 signals to an audio output.

1 52. A signal processing system, comprising:

2 an input signal channel providing digital input signals;

3 means for calculating a power spectrum for said digital input signals;

4 means for applying a second difference operator to said power spectrum to
5 locate a plurality of power spectrum peaks;

means for amplifying said plurality of power spectrum peaks to achieve a modified power spectrum; and

8 means for producing a digital output signal from said modified power
9 spectrum.

1 54. The signal processing system of claim 53, wherein said amplifying
2 means applies a scaling factor to the amplification applied to each of said plurality of
3 power spectrum peaks, said scaling factor based on the determined sharpness of the peak.

1 55. A method of processing sound in a hearing aid, comprising the
2 steps of:

3 receiving digital input signals;

4 passing a portion of said digital input signals through a plurality of
5 cascaded all-pass filters to form a sequence of delayed samples;

6 windowing said sequence of delayed samples;

7 applying a frequency domain transform to said windowed sequence of
8 delayed samples to form a warped sequence;

9 calculating a plurality of frequency domain level estimates from said
10 warped sequence;
11 calculating a plurality of frequency domain gain coefficients from said
12 plurality of frequency domain level estimates to form a warped time-domain filter;
13 calculating a plurality of spectral enhancement gain coefficients from said
14 warped sequence;
15 calculating a plurality of compression-spectral enhancement gain
16 coefficients from said plurality of frequency domain gain coefficients and said plurality of
17 spectral enhancement gain coefficients;
18 applying an inverse frequency domain transform on said plurality of
19 compression-spectral enhancement gain coefficients to form a set of time-domain filter
20 coefficients; and
21 convolving said sequence of delayed samples with said set of time-domain
22 filter coefficients to produce a digital output signal.

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